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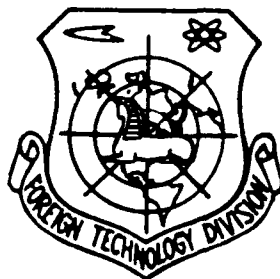
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INFLUENCE OF FLOW VELOCITY ON THE OUTPUT POWER OF
HIGH PRESSURE CW CO₂ LASERS

by

Chu Zexiang, Chen Liyin, Wu Zhongxiang



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**TITLE: INFLUENCE OF FLOW VELOCITY ON THE OUTPUT POWER OF
HIGH PRESSURE CW CO₂ LASERS**

AUTHOR: Chu Zexiang Chen Liyin Wu Zhongxiang

In the past, when we have done studies at operating pressures of 20 Torr, of effects of relatively large flow speeds (20-340 m/s) on laser functions^[1-3], we have also discussed the special characteristics of high pressure CW CO₂ lasers within a range of operating pressures which was 40 Torr ~ 2 atm when flow velocities were fixed at 70 m/s^[4]. This article will take a step further studies of the overall effects of flow speed and pressure on CO₂ laser device characteristics within a range of even greater flow speeds (30 ~ 340 m/s) and high pressures (40 ~ 760 Torr), taking the occasion to investigate the potential displayed by high pressure instruments.

See Fig.1 for the equipment being considered. Calculation models and equations are the same as in [1]. Assume that the electron density n_e , in the right cylinder area along the direction x , is evenly distributed. One will set up simultaneously and solve conservation equations associated with one dimensional ideal gases and relaxation equations associated with three vibration or oscillation model systems. Satisfying certain stable oscillation conditions, one calculates out saturation and gain and output power. The calculation parameters are: $\varphi_{CO_2}:\varphi_{N_2}:\varphi_{Ne} = 0.05:0.27:0.27:0.68$; $P_0 = 40 \sim 760$ Torr; $U_0 = 30 \sim 340$ m/s; $T_0 = 293$ K; $E/N = 2.2 \times 10^{-16}$ V·cm²; $A = 10$ A. The degree of output coupling $C = 0.08$.

Considering the lens length to be 5 cm and the lens height to be 3 cm, under conditions of relatively high pressure, we select the x light cavity or chamber position to be 0.5-5.5 cm. Primary consideration is placed on positions where output light powers are relatively high, lying close to the upper reaches of the gas flow. Besides this, under low pressures, the range of permissible degrees of output power coupling is relatively large. Under high pressure, the range becomes narrow. Under various types of pressures, in actuality, there are no common optimum degrees of coupling. In order to facilitate comparisons against different pressures and flow velocities, in conjunction with this, reference [5] appropriately selects the degree of output coupling to be 8%. This degree of coupling, within the range of pressures of the article in question, in

all cases, is in the vicinity of the optimum degrees of coupling. This guarantees that all comparisons are carried out within a range of relatively good degrees of coupling. Under the conditions above, when calculating out different pressures, the relationships of flow velocity and output power are seen in Fig.2.

Generally speaking, with regard to certain fixed operating pressures, initial output powers follow increases in flow speed and increase. At a certain speed, the output power reaches maximum values. After this, it follows flow speed increases and gradually gets smaller. From Fig.2, one sees that, at relatively low pressures ($P_0 < 100$ Torr), the power curve is relatively gentle. The explanation for this is that, at relatively low pressures, the influence of flow speed on output power is not obvious. However at high pressures,

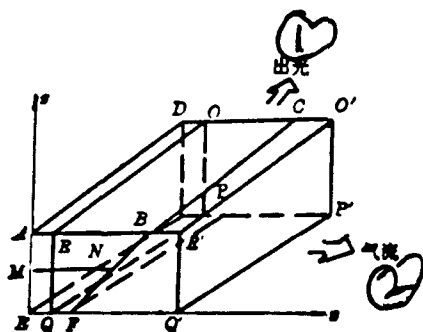


Fig.1 Laser System Diagram MN=5.5cm, AE=3cm, AD=100cm, AB is the anode. EF is the cathode. QQ'R'R, PP'O'O is the Resonance Cavity Lens (1) Output Light (2) Gas Flow

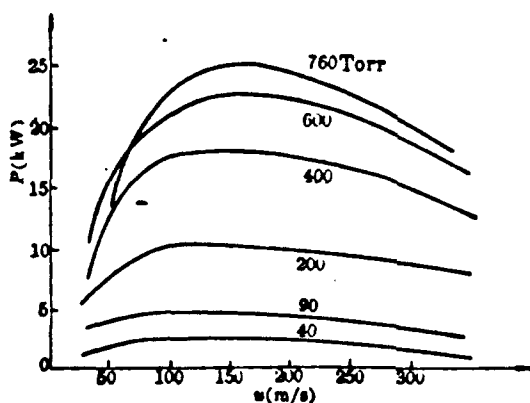


Fig.2 Relationships Between Flow Speed and Output Power When Pressures Vary

$(P_0 > 200 \text{ Torr})$, the influences of flow speed on laser device output powers are relatively obvious. Following along with increases in gas pressure, the ascents and descents of curves are even more abrupt. This goes to the point where, when pressure increased to 760 Torr and flow speed is 50 m/s, the output power is 13.62 kW. On the other hand, compared to when $P_0 = 600 \text{ Torr}$, the output power of 15.40 kW will still be somewhat small. When flow speed is 30 m/s and pressure is 760 Torr, gain is extremely small, leading to not being able to attain the necessary conditions for stable oscillation. This is due to the fact that, following along with increases in pressure, activated media cross sections flowing through instruments in a unit time increase, causing, in a unit volume, increases in the available laser energy. However, due to the fact that this is excessively slow, gas flows in light cavities have relatively long retention or delay times. In lasers, upper energy level collisions eliminating emissions also abruptly increases due to increases in pressure. These two types of factors mutually increase and decrease. When pressures are adequately large, this leads to a drop in output power. To summarize, output power follows patterns or rules for changes in flow speed which are relatively complicated. It is not possible to only consider them in terms of speed of heat radiation and high or low temperatures. Moreover, it is necessary to consider, under the effects of electrical discharges and radiation fields, the competition and the reciprocal rising and falling effects between various types of energy transmission rates associated with pumps and relaxation, which are received from upper and lower energy states of non-equilibrium flow media, making investigations from the perspectives of the mechanisms of media flow speeds and micromechanics or kinetics. During high pressure operations, it is necessary to consider media flow speeds in an even more detailed manner. Under different pressures, there are corresponding optimum flow speeds in all cases. As far as the instruments in this article are concerned, when $P_0 > 200$ (illegible) Torr, the optimum flow speed is between approximately 125~150 m/s.

Fig.3 is the relationships between flow speeds and laser device photoelectric exchange efficiencies under different pressures. From the Fig., it can be seen that, when pressures are relatively low ($P \leq 90$ Torr), following along with increases in flow speed, efficiency drops monotonically. However, when pressure is high ($P_0 \geq 200$ Torr), as far as each different pressure is concerned, efficiencies are all capable, when there is a certain flow speed value, of reaching a maximum value. Following along with increases in pressure, the rises and falls of efficiency curves turn even more abrupt. The reason for this is that, following along with changes in pressure, the effects of flow speed on efficiency are even greater. From the Fig.'s, it is possible to see that, when flow speeds are relatively low, when pressures are at 40~90 Torr, laser device

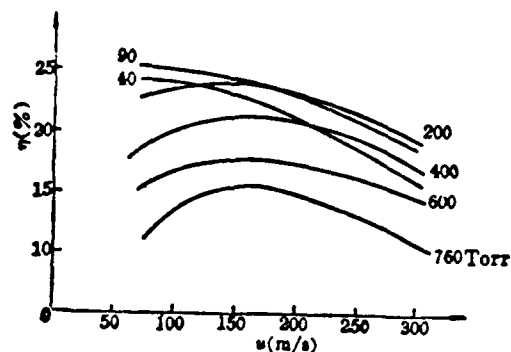


Fig.3 Relationships of Flow Speed and Efficiency When Pressures Vary

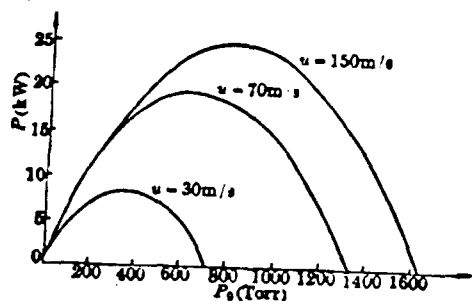


Fig.4 Laser Output Powers With Different Flow Speeds Vary

efficiencies are relatively high. When flow speeds are relatively high and pressures are $90 \sim 200$ Torr, the efficiencies are also relatively high. When the pressure $P_0 > 200$ Torr, efficiency follows increases in pressure and goes down.

Fig.4 gives the relationships between changes in flow speed and output powers and instrument pressures. It is possible to see that, following along with flow speed increases, the range of pressures which are permissible for instrument operation becomes larger. The corresponding maximum output powers also increase. When flow speed is $u = 30$ m/s, and the range of instrument operating pressures is 0-720 Torr, the maximum output power ~ 8 kW. When flow speed is $u = 70$ m/s, and the range of pressures is $0 \sim 1.7$ atm, maximum output power ~ 20 kW. When $u = 150$ m/s, and the range of instrument pressures is $0 \sim 2.1$ atm, maximum output powers ~ 25 kW. From the discussion above, it is possible to see that appropriate increases in flow speed are capable of making the range of instrument operating pressures expand. Output powers increase, giving, as far as possible, a theoretical basis to increases in the output powers of laser instruments.

Below, we will concentrate our studies on the laser device gain from flow speed when in a one atmosphere pressure ($P_0 = 760$ Torr), level or smooth movements and the temperatures of degrees of vibration, as well as the influences associated with the ranges of degrees of output coupling.

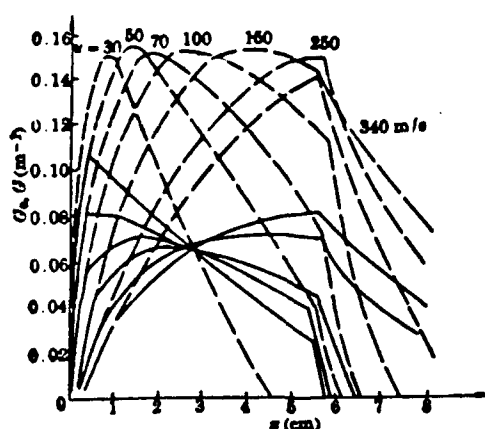


Fig.5 Changes Along the Direction of Flow x in Small Signal Gain and Saturation Gain When Flow Speeds Vary

Fig.5 is changes along the flow direction x for small signal gain and saturation gain when flow speeds are different. From the Fig., one is able to see that, with flow speed at $30 \sim 340$ m/s, peak values for small signal gains are fairly close to each other and are approximately 0.15m^{-1} . However, the trends associated with the rising and falling of curves are still different from each other. When flow speed is relatively small, the increases and decreases in small signal gain curves are all relatively fast. Gain areas or zones are very small. Corresponding saturation gains follow along with increases in x and abruptly go down. When flow speed increases to $u = 100 \sim 250$ m/s, increases and decreases in gain curves are all relatively slow. Gain areas or zones are relatively gentle. Corresponding saturation gain values are relatively low in the entire light cavity area. Changes are very gentle and stable. At this time, the powers which are capable of being selected, as far as the light cavity area is concerned, are also, correspondingly, relatively large. However, as far as going a step further with increases in flow speed is concerned, if $u = 340$ m/s, increases in small signal gain are very slow. The peak values are 0.14m^{-1} . Corresponding increases in saturation gain curves are very slow. Saturation gain values are also relatively high. In light cavity areas, powers which it is possible to select are still definitely not numerous. This may be due to the fact that, in cases where flow speeds are excessive, when laser media flow through light cavity areas, the delay or retention times are correspondingly relatively short. They lack the ability to adequately take effect. As a result of this, output powers are certainly not large. In summary, from the Fig., one is able to see that gain areas corresponding to optimum flow times are relatively open and gentle. Saturation gain values are relatively low. At this time, output powers are maximum.

Fig.6 is the changes along the direction of flow movement x for vibration temperatures T_3 and TP_0 associated with energy level $N_2(v=1)$ and $CO_2(001)$ as well as the level or smooth movement

temperature T for different flow speeds, with $P_0=760$ Torr. Due to the fact that $\text{CO}_2(100)$ and $\text{CO}_2(010)$ energy level vibration temperatures and level or smooth movement temperatures do not differ from each other very much, as a result, in the Fig., they are not drawn out. From the Fig., it is possible to see that the level or smooth movement temperature T follows along with increases in flow speed and goes down. This reflects the effects of flow speed on the elimination of waste heat. Outside light cavity areas ($x > x_0$), due to the fact that light radiation is stopped, level or smooth movement temperatures go up slightly. Due to the effects of electrical excitation, after media enter electrical discharge areas, the number of particles of energy levels $\text{CO}_2(001)$ and $\text{N}_2(v=1)$ rapidly increases. The corresponding temperatures of vibration T_S and T_N rapidly go up. The larger medium flow speed becomes, the more correspondingly delayed this type of increase is. When flow speeds are relatively small, if $u = 50$ m/s, laser media have been adequately excited electrically. As a result of this, when entering light cavity areas, vibration temperatures T_3 and T_N are, then, relatively high. Within light cavities, due to the common effects of receiving electrical excitation and radiation, vibration temperatures go up and down to some degree. Because flow speeds are relatively small, vibration temperatures are still placed at relatively high values. When one selects the optimum flow speed $u = 150$ m/s, the changes in vibration temperatures in light cavities are relatively smooth and stable. In areas of media outflow electrical discharge, due to the fact that there are no effects associated with electrical excitation or activation, energy level vibration temperatures in lasers under various types of flow speeds all clearly go down. The larger the flow speed is, the gentler the decline is.

Fig.7 is the relationships between flow speed and degree of output coupling when $P_0=760$ Torr. From it, it is possible to see that, following along with increases in flow speed ($u = 70 \sim 150$ m/s), the range of the degrees of output coupling also is enlarged. The corresponding optimum rates of coupling show slight increases. Maximum output powers also show some increase. When flow speeds take another step in their increases ($u = 200 \sim 340$ m/s), the range of the

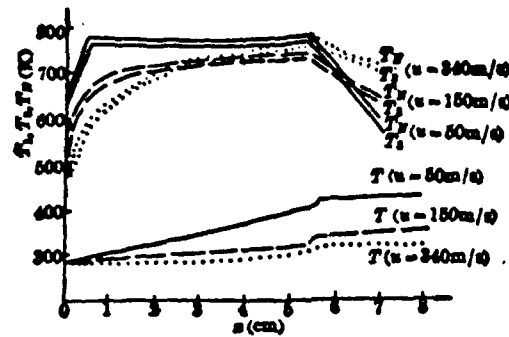


Fig.6 Changes Along Flow Direction x in Level Movement and Vibration Temperatures When Flow Speeds Vary

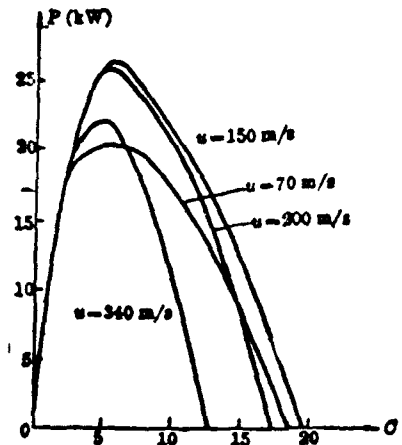


Fig.7 The Relationships Between Degrees of Coupling and Output Powers When Flow Speeds Vary

degrees of output coupling, on the contrary, follow them and get smaller. The corresponding degrees of maximum coupling and maximum output powers also get smaller. This is the same as saying that, following along with increases in flow speed, cut off degrees of coupling also have an extremely large value. This extremely large value and maximum flow speeds correspond with each other. It is only when one has the selection of optimum rates of coupling with optimum flow speeds that one then achieves maximum output powers for the instruments.

As far as the results and rules or patterns which this article obtained are concerned, it is possible for them to supply a basis and reference for the design of and research into high pressure flow CO_2 laser devices.

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